



RCA INSTITUTES

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Technical Lesson 3

THE ELECTRON THEORY - SUBSTANCE AND MATTER - STATIC ELECTRICITY.

INTRODUCTION. It might be said that anyone who decides to study the science of radio and electricity introduces himself into a world of unseen forces, or into what is virtually a realm of tremendous activity and agitation. If all of the human beings on this earth were permitted to peer into the mysteries of our world through a huge magnifying glass, one equipped with a lens having a magnification thousands of times greater than the most powerful in use today, it is thought that we would be privileged to gaze upon billions and billions of tiny universes consisting of diminutive specks or particles. Each and every one of these particles is supposed to have all of the three qualities that would entitle them to be classified as tiny bits of matter. These qualities are size, weight and mass, and moreover, each particle would be found to possess a very definite amount of energy. Energy can not be created by man in anyway whatsoever; the energy existing in the particles is a natural condition and is a part of all things creative, a condition over which we have no control and know little about.

The great privilege of seeing these bits of matter is not yet within the reach of man even with all of the available scientific apparatus because of the natural limitations of our eyesight. We wonder, then, how small these very tiny things really are.

The principal constituents of these minute universes have been given the names, molecule, atom and electron. For years scientists have labored to tear down the clouds of uncertainty surrounding these minute bodies in order that they may learn more about their physical make-up and the particular quality which has been given the name energy. How well these tireless laboratory workers have succeeded in putting natural forces to work could never be fully realized except that through some extraordinary calamity everything electrical were suddenly taken from us.

If you could visit the scientific laboratories of Dr. Langmuir, Dr. Coolidge, Dr. Millikan or Dr. Alexanderson and other men of equal prominence, and witness the many marvelous experiments in progress, and see the wonderful things that are accomplished when the power locked up in a molecule is utilized, you would appreciate why we have introduced this lesson on radio and electricity in this way. If you could watch these scientific investigators at work you would undoubtedly forget, at least for the time, about all of the ordinary things in your daily existence.

The predominating scientific thought of today teaches us that everything we see or feel is electrical in nature, and this despite the fact that we may not be aware of it. The development of such an idea has been a slow one, because it required many proofs to substantiate it, and these proofs could be obtained only through logical reasoning and simple deductions following years of experimentation and research. The idea is now moulded

into a well-founded theory, called the "Electron Theory". This theory is used by practically all scientific men to account for different electrical phenomena and, therefore, its importance to us cannot be overestimated.

The "Electron Theory", explained in subsequent paragraphs, is based upon the combined action of the "negative electron", the very smallest speck of matter which is negative electricity, and a complementary particle of positive electricity. One authority calls the latter a "positive electron", but it is more commonly spoken of as a "proton". These electrical charges not only form the basis of all matter itself, but are the cause of all electrical actions. Thus, to better understand electrical forces and their practical application it is necessary to have some general information concerning the construction of matter.

MATTER. All normal human beings are gifted with five faculties or sensations; these are sight, taste, hearing, touch and smell.

Scientists tell us that anything which occupies space and acts on our senses is matter. If we accept this statement we should have no difficulty in understanding that objects, such as chairs, tables, houses, radio sets, the wires used to connect up radio parts, aircraft, the very paper and ink used to print this lesson, and even the air you breathe, are all examples of matter. Again, anything which occupies space and has weight is said to be matter.

Matter taken as a whole exists in three different forms, namely,

SOLIDS, LIQUIDS and GASES.

A solid is a body which offers an opposition to any change in its shape when under normal temperature and pressure. An object, such as a piece of iron, will keep its shape and identity just so long as it is protected from the elements, or from abnormal temperatures or pressures.

However, we know that if iron is placed in a blacksmith's forge and heated it can be worked into any desired shape by constant pounding with a hammer. Striking the hot iron with a hammer exerts a certain pressure and the hot fire increases the temperature; it is clear that these two provisions are necessary before the iron can be properly worked. Now, suppose this iron remains in the fire bed and the heat is considerably raised by operating the forge blower; it is evident that a time will come when the solid piece of iron will become molten and then being converted to a liquid it will either form a pool, or run off, or flow as would any heavy fluid. If the liquid iron was poured into a receptacle, or mould, and allowed to cool it would assume the shape of the receptacle.

Water is a very good example of matter which can be easily changed into any one of three forms. Water in a natural state is a colorless liquid; when frozen it turns into a solid cake of ice; and when heated to the boiling point steam will issue forth from its surface and rapidly expand into the surrounding space as a gas. See Figure 1. In general, all forms of matter have four important properties. They are:

POROSITY, COMPRESSIBILITY, ELASTICITY and DIVISIBILITY.

(a) Porosity may be defined as the existence of minute openings or pores in any kind of matter, the openings or pores being entirely void of any of the material or substance of which the matter is composed. Each pore, regardless of its size is really empty space. These openings vary in size for different materials as may be seen by inspecting a section of soft wood and comparing it with a piece of marble or iron. The common blotter which absorbs ink is a good example of porosity. Also, water is capable of taking into its pores a definite amount of dissolved sugar without noticeably increasing the bulk of the water.

(b) Compressibility may be considered to be a general property of all matter which would permit the small particles composing the matter to be more closely packed together. This packing would tend to lessen the amount of the void spaces within the mass. Pressure applied to any substance acts to compress it. A hot ingot of iron after passing through heavy steel rollers in a steel mill will emerge in compressed form. In the case of water and oil we have forms of matter which almost resist compressing, but such liquids, however, may be compressed to a very limited degree by the application of great pressure. In all events the amount of compression depends upon the pressure exerted and the kind of matter under compression.

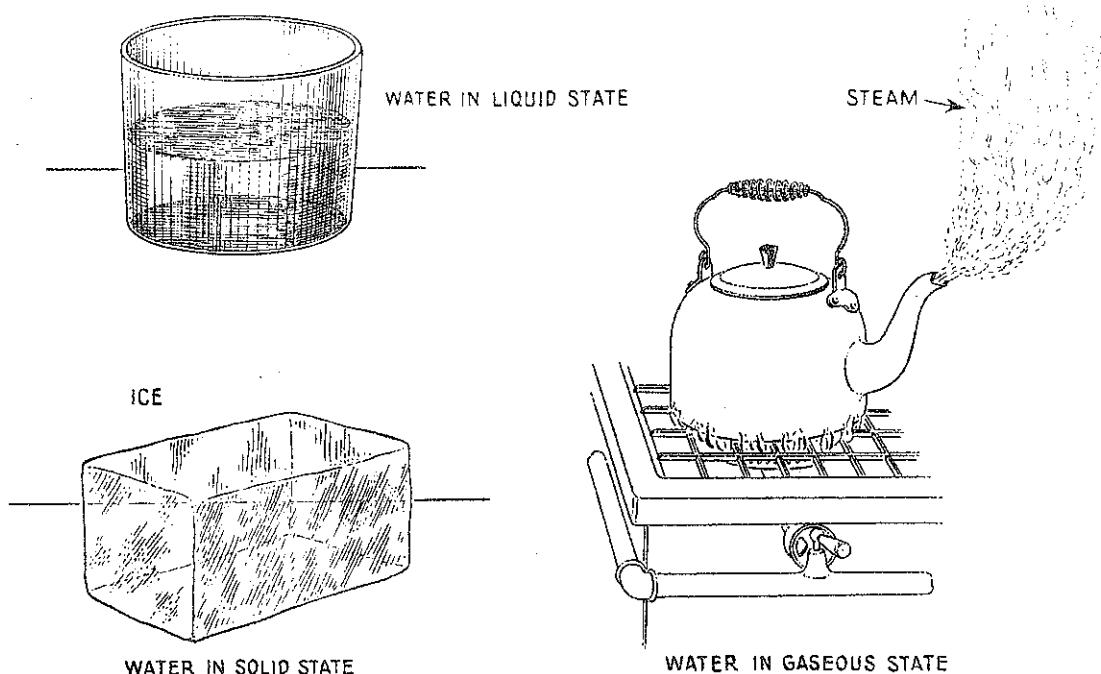


Figure 1

(c) Elasticity in matter may relate either to elasticity of physical form or elasticity of volume. This term is used to designate the property possessed by solid bodies that permits them to be stretched to certain limits without breaking and, later, to return to their original shapes after the stretching force or pressure is removed. When force is applied to a material in a way that will cause it to become twisted, bent, or stretched, the molecules which form the material are distorted and displaced under an unnatural strain. If the force is discontinued the molecules will try to adjust themselves and shift back into their usual places as quickly as possible.

This property, known as "elasticity", can be demonstrated by pulling a rubber band and then letting it go. It is this property of elasticity that permits heavy weights to be supported with safety. It would require a far greater force to pull a copper wire in two than a piece of silk. Thus, we would say that the wire has greater tenacity than the silk, or we might say the molecules forming the wire will not "let go" as readily as would the molecules of silk. All solids and liquids and gases have elasticity to a greater or less extent.

If force is applied in constantly bending a material heat will be generated. This is due to the rubbing together of the molecules as they are forced out of their relative positions; we say that the heat is due to molecular friction.

(d) Divisibility of matter relates to the division or breaking up of matter into its smallest conceivable parts without in any way altering the form of matter itself. Just how small such particles of matter may actually become, and still retain their identity, can be demonstrated by allowing a few drops of colored ink to fall into a glass of water. At first, the ink will be seen to form irregular streaks which work downward through the liquid. If the glass is left undisturbed for some time it will be noticed that all of the liquid will become colored. Can you imagine how tiny these divided ink particles (from only a few drops) must have been to permit them to enter the countless pores in the comparatively large volume of water, and cause the water to be uniformly colored throughout?

Hence, we learn that matter is not absolutely a solid homogeneous structure, but that matter is made up of countless billions of extremely little particles with non-material spaces, called "voids", separating the particles.

The exceedingly minute particles which we have been speaking about are given the name molecules.

The tiny specks, called molecules, are never absolutely motionless under average conditions.

MOLECULES: A molecule is defined as the smallest division of any kind of matter retaining all of the chemical and physical properties of the matter itself. Therefore, a molecule, although very small, can be identified as belonging to a particular kind of matter.

As a body is lowered in temperature, that is, as it gets colder, the movements of the molecules become less violent. On the contrary, when a body is raised in temperature, that is, as it gets hotter, the molecular movement becomes increasingly more active. It is only at the very lowest known temperature (absolute zero) that the molecules of all matter are dormant, meaning that all action ceases. Absolute zero is about 459 degrees below zero and is the point at which no heat can be given up or taken from a body. Speaking in broad terms we can say that heat encourages molecular vibration, or motion, whereas cold tends to counteract it.

ATOMS. The molecule itself is composed of an aggregation of atoms, the atoms being the smallest parts into which matter can be divided by chemical means. The tendency of atoms of a similar kind (or specie) is to assemble together and form molecular groups which in turn become units of matter. Once the groups are assembled they resist all ordinary methods to disrupt or tear them apart. The application of a force, or heat, are two means for

effectively overcoming the strong molecular attraction inherent in all matter. An atom consists essentially of positive and negative electricity with the atoms of the various materials differing in their general formation.

There are more than ninety different species, or kinds, of atoms some of which are familiar to all of us; for example, we have the copper atom, the iron atom, the gold atom, the hydrogen atom, and so on. The individual atoms in any one specie are practically identical but the different species have totally different properties.

ELEMENTS. Every molecule which forms a given substance must consist of the same number and same specie of atoms, and to express this fact we give the substance the name element. Taking any of the elements singly, each one consists of only one kind of atom. Hence, we understand now why copper, sulphur, iridium, oxygen, carbon, lead, gold and all the rest of the ninety or more elements each exhibit their individual properties by which we know them. When different kinds of atoms combine the substance formed is called a COMPOUND.

You can better understand these terms by analyzing how water is formed. Water, as we know it, is simply a colorless liquid. A molecule of water is the smallest divisible part of water that can possibly be obtained with the molecule retaining the identity of water. However, the molecule is composed of two elements, neither one of which resembles water.

These elements are hydrogen and oxygen, two gases which always combine in the same amounts when brought together. To cite an example: It takes two atoms of hydrogen to enter into combination with one atom of oxygen to form one molecule of water, and using the symbols, we have the chemical expression for water, H_2O . Water molecules are a very simple arrangement in the atomic world when compared with certain compounded substances. We have, for example, a very complex aggregation of different specie of atoms in a molecule of sugar. To form one molecule of sugar requires twelve atoms of carbon, twenty-two atoms of hydrogen and eleven atoms of oxygen combined into a single group. There are countless numbers of possible molecular combinations which permit the formation of the many different kinds of things found in and about this world of ours.

COHESION. There is a tremendous mutual force of attraction between atoms of certain kinds that causes them to form groups, and because the atoms possess this property the molecules which they form also have it. Thus, we see why there is a strong tendency for things to hold or cling together, or remain intact — this property of matter is called cohesion.

You might be surprised to learn that it is not a simple matter to pull a sheet of paper apart. Why not try to do this right now and convince yourself. Take a sheet of writing paper, roll it and then grasp it at either end and pull with all your effort. Were you successful in pulling the paper into two parts? While you can tear this paper easily, you may not be able to force the molecules to give up their clinging hold on one another.

The term "adhesion" is often confused with "cohesion". Adhesion is used to express the mutual forces that hold molecules of dissimilar kind together. Butter will stick to bread because of adhesion, but the butter or bread considered alone hold together because of cohesion.

ELECTRICITY IS DIVIDED GENERALLY INTO TWO CLASSES. In the broad sense electricity is divided into two classifications, namely: static electricity and dynamic or current electricity. In this lesson we give a brief outline of important early experiments which deal mainly with static electricity. You will see that many electrical principles can be explained and proved by the simplest facts of nature and by laboratory experiments.

Important Events Leading up to the Establishment of the Electron Theory. Going back to the year 600 B.C. we find that in the Grecian city of Miletus, there was a Greek philosopher, named Thales, who pondered over the causes for lightning and tried to ascertain why it had such destructive effects. During one of these periods of study he discovered, quite by accident, that if an amber rod was rubbed with a piece of silk the rod at once possessed the power to attract small bits of parchment. Later, during the period of 400 B.C., Democritus devoted considerable time to the study of materials and effects which could be produced by them, when treated in various ways. His interest was aroused when he observed that in some instances an attraction was set up between certain substances when rubbed together, whereas, between other substances there was the effect of repulsion set up.

These experiments are thought to be among the very first recorded concerning the discovery of a source of electricity, and since the effects were brought about by friction this kind of electricity became known as "electricity at rest". But we now call effects of this kind "static electricity". The ancient Greeks attempted to account for the mysterious results obtained when rubbing together materials of different kinds. One of the reasons they advanced in explanation of such effects was that during the rubbing process small grains of one material were being imparted to the other material.

In 1600 Dr. Gilbert of England performed experiments similar to those of the Greeks. But where they used amber he employed a glass rod, and observed that the materials could be put into a condition that would give them the power of attraction or repulsion as the case may be. It was Dr. Gilbert who applied the Greek word for amber, which is "elektron", to express these peculiar effects and he stated that when the glass rod was rubbed it became "electrified". The electrification of bodies when subjected to such treatment was shown to be merely a temporary condition and although the exact nature of the electrical charge was not known the results attained indicated that the static charge rested only on the outer surface of the electrified material.

In 1733 Dr. Dufay, when engaged in frictional electrical experiments, noticed that sealing wax, when rubbed with cat's fur, became electrified and possessed qualities unlike those of a piece of glass which had been electrified by rubbing with cat's fur. He saw that the sealing wax would repel substances for which the glass, on the contrary, would exhibit a decided attraction.

Moreover, he sought to identify these properties of opposite kind. Accordingly, he gave the name "resinous electricity" to the charge possessed by sealing wax when rubbed with cat's fur and the name "vitreous electricity" to the charge taken on by glass when subjected to frictional contact with the cat's fur. Thus, we must learn at the start that the terms positive and negative in all electrical science are merely relative and arbitrary as

originated by Franklin. Indeed, he could have called resinous and vitreous electricity by totally different names so long as the names he did apply served to illustrate the important fact: "Whenever electricity is evident there always exists simultaneously two unlike electrical charges of equal quantity". You cannot have one kind of charge present without the other. The words "positive" and "negative" seemed to fit the requirements and they have been used as standard terms ever since.

Meaning of "Positive" and "Negative". We are indebted to Benjamin Franklin for originating what are undoubtedly the two most commonly used terms in electricity; positive and negative. About the year 1747, after considerable experimental work, he observed that whenever electricity of one kind was present there also was present an opposite kind. In other words, we could not have one condition of electricity prevailing without also the opposite condition. From this fundamental idea we are able to account for the effects of attraction and repulsion. Franklin suggested that the state of charge be given the following arbitrary terms, thus: "A substance is said to be positively electrified if it is repelled when coming into contact with a glass rod after the latter has been electrified by rubbing with silk. On the other hand, a substance is said to be negatively electrified, or charged to a negative sense, if sealing wax repels it after the wax has been electrified with cat's fur".

It is interesting to note that in the early days learned men believed electricity was due to the flow of an invisible liquid. Indeed, even to present time we use the word "flow" to express the movement of an electrical charge from one place to another. In our everyday work we often hear someone make the following remark: "A flow of current in a certain conductor produced such and such a result, etc." Thus, the term "flow" has been retained despite the fact that the fluid theory has long since been discarded.

In 1833 Faraday also contributed theories concerning the electrical effects resulting from friction between substances. He conceived the idea that when materials were rubbed together, they were placed under an electrical influence, or stress, and that some unknown intervening medium was capable of carrying this stress along the material. This is precisely what happens when a glass rod is rubbed with a silk cloth. This conception was really important because it was the forerunner of the idea that the surrounding "space medium" was a carrier of an electrical charge.

Furthermore, it is important to mention that Faraday discovered that a distinct relationship existed between substance and current. This relationship was observed by him when performing an experiment employing a jar containing a solution into which was immersed a copper rod and a silver rod. He noticed that a certain amount of current was required to maintain a chemical reaction that would remove a certain quantity of silver from the silver rod and deposit it on the copper.

After Stoney's suggestion in 1891 that the "electron be known as the natural unit of electricity" the electron theory became permanently established. But notwithstanding the many years of diligent research, as just outlined in our lesson, the question, "What is electricity?" remains unanswered to this day. No one is certain as to the actual nature of electricity.

The Electron Theory Accounts For Electrical Forces and Their Effects. At the present time the electron theory prevails almost universally. It is based on the very nature and composition of all matter; solid, liquids, and gases. All forms of research are vitally important because as modern science delves closer and closer into the fundamental basis of our universe it daily contributes new knowledge which makes possible the rapid development and improvement in radio design and equipment.

Getting down to the last analysis of matter, or its real composition, we are told that it is all made up with infinitesimally small matter particles which are essentially electrical charges. These unit charges of matter have been given the names, electrons and protons. In brief, all electrons possess a definite amount of negative electrical energy, also, they constantly whirl about their positive nucleus at tremendous high velocities, besides which they occupy a certain place in the complicated system in the atoms of matter. In our work we deal chiefly with the "electron" and simply refer to the "proton" as the positive charge or nucleus. The exact arrangement of this atomic system depends upon and differs according to various kinds of matter. Refer to Figure 2, where there are shown three different atoms, each with an inner group of electrons circling about a positive center of attraction, and "free" electrons racing about at high velocity to form a so-called outer group. Note that because of their position the free electrons could be more easily detached from an atom than any of the electrons forming the inner group.

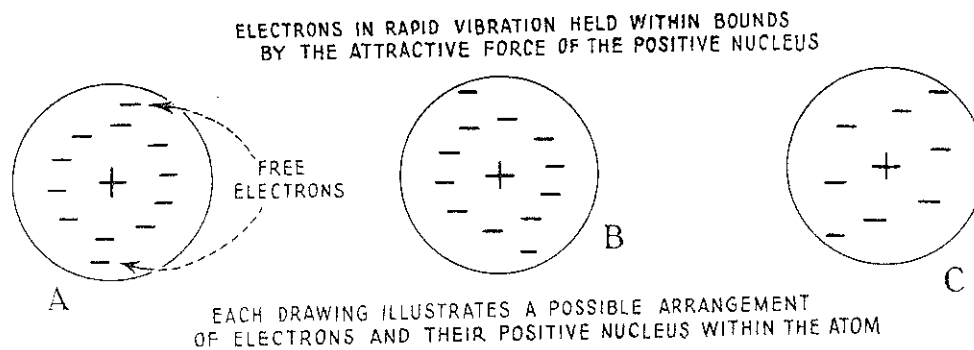


Figure 2

This hypothesis, wherein atoms of matter are thought to be made up of electrons, or particles of electricity, teaches us that electricity and matter are fundamentally the same. Before you are through with this subject you will not only learn that all matter is made up of a very complex and wonderful structure of atoms, but that the basis of all things is the small unseen electrical particle "the electron".

FRICTIONAL OR STATIC ELECTRICITY

Let us now return to our subject and discuss in detail the results of performing a simple experiment where two dissimilar substances are rubbed together, and electrical forces are developed. There is no movement to electrical forces of this kind in the ordinary sense that one usually thinks of movement; the forces are "stationary", or better expressed as "electricity at rest". Forces of this kind are known as "static electricity" and the subject itself is referred to in general as ELECTROSTATICS.

It will be shown that static electricity produces effects which are independent and different from those resulting from "electricity in motion". The latter kind of electricity is classified in general as dynamic electricity, or as CURRENT ELECTRICITY. This is the electricity that flows through copper wires and other conducting mediums and is referred to in general as ELECTRODYNAMICS.

How to Produce Static Electricity by Simple Methods. It is an easy matter for us to observe the effects of static electricity produced on materials by rubbing them together. To do this follow the instructions as suggested in Figures 3 and 4. Take an ordinary rubber comb and with the back held against a piece of wool rub the comb briskly back and forth across the wool. The comb is now electrified. If you now move it close to small bits of paper, which have been prepared for the experiment, a very strange influence will be seen to exist in the region about the comb. You will notice as the comb is moved slowly toward the little paper bits that they will be strongly attracted to it; the bits will actually jump toward the comb and adhere to it for a few moments. Next, as you watch this action, you will observe another peculiar effect, for after a short interval the bits of paper will seem to be thrown forcibly away from the comb. That is to say, the paper bits do not merely drop off but seem to be actually repelled. In the first part of the experiment the property of attraction between the materials was observed and, lastly, the property of repulsion was clearly exhibited. This is only one of many effects which may be brought about by static electricity due to friction.

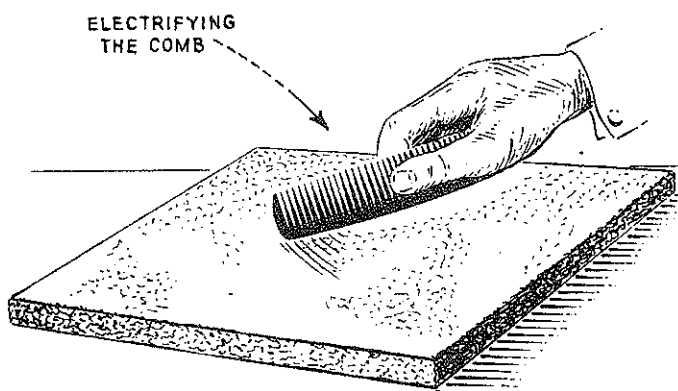


Figure 3

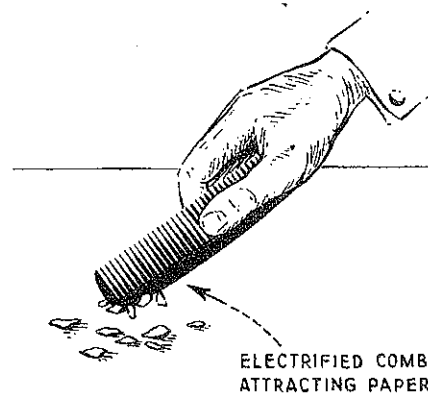


Figure 4

Inasmuch as the comb at different times evidences qualities which were opposite electrically, that is, alternately indicating attraction and repulsion, then it sets us to thinking that unseen forces must have been constantly at work while this entire experiment was under way. It is quite apparent that two distinct kinds of electric (static) charges were present in order to produce these results.

Let us experiment further and perform a simple test similar to one made by Franklin in 1747. His purpose at the time was to evolve standard terms to be used in explaining actions relating to electrical (static) forces from known conditions. Our purpose, it is quite obvious, is merely to learn about this marvelous science and so let us set up the experiment as illustrated in Figure 5 and 6. A glass rod and an ebony rod are each suspended by a silk

thread at some distance from each other as shown in the drawing. A second glass rod will be used to produce the desired effects by touching it first to one of the suspended rods and then the other. Now, with a brisk movement, rub the ebony with a piece of fur and then follow by rubbing each glass rod in succession with a piece of silk.

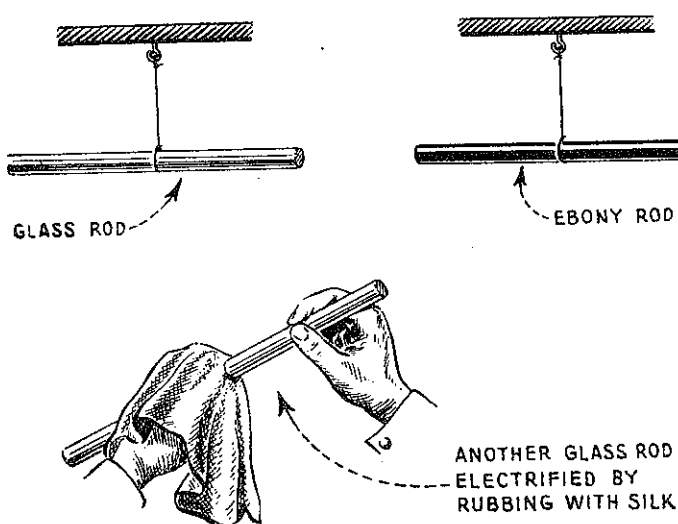


Figure 5

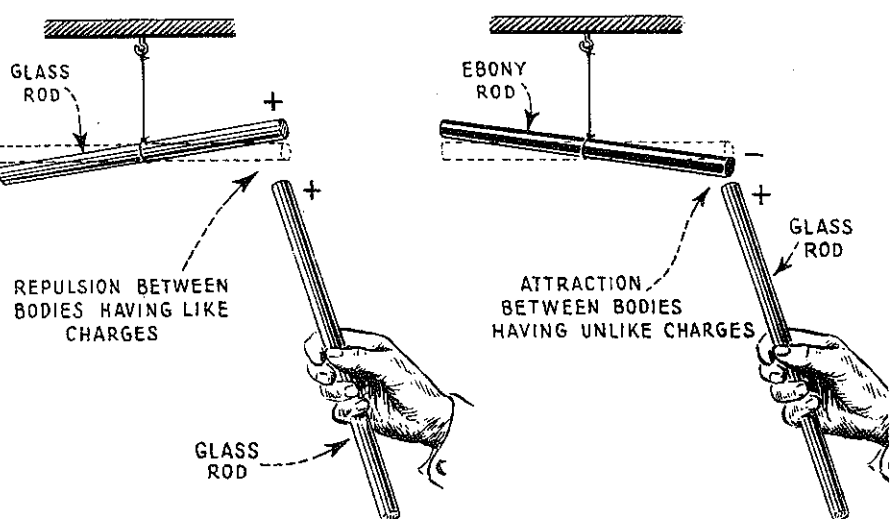


Figure 6

All of the three rods are now said to be statically charged or electrified. Take the unsupported glass rod and hold it near the ebony rod. The ebony rod will at once swing toward the glass rod thus denoting the presence of an attractive influence. This time place the glass rod, held in the hand, close to the supported glass rod. The latter will be seen to swing away instantly, thus denoting the presence of a repulsive influence. The sketches in Figures 7 and 8 illustrate attraction and repulsion effects in static electricity.

ELECTRIC-STATIC FIELD. The experiment in Figure 6 shows how one electrically charged body exercises an influence on another charged body when placed in close proximity with each other. The drawings in Figures 7 and 8 are a simple means for showing how "lines of force" which are called static lines of force, reach out a considerable distance and occupy the space surrounding an electrified body. These lines are, of course, invisible but the static electrical actions are accounted for by their presence.

A "force" is always indicated by a line and the direction of the arrow head at the end of the line denotes the direction in which the force is applied. Also, understand that the individual lines show repulsion for one another and it is this peculiarity that causes them to remain apart and assume the formation shown in the drawings. All of the lines taken as a whole are called a static field of force. The space surrounding a charged body is filled with these static force lines, with the effect of each individual line ending on the outer surface of the material.

From this test we see why a strong attraction existed between the ebony and glass rods and a pronounced repulsion between the two glass rods. We can now summarize this by stating that the materials were placed in this con-

dition by rubbing and that two kinds of electric (static) charges were made evident; this is indicated by the polarity signs (+) and (-) in Figure 6.

STATIC CHARGES ARE DUE TO A DISPLACEMENT OF ELECTRONS WITHIN THE ATOM. With the tests just performed in mind and explanations to follow we will learn why materials exhibit totally different actions when electrified by friction. The fact that glass and fur when rubbed together show contrary electrical behaviors is quite significant. To give a reason why one has the power to "attract", and the other the power to "repel", we must refer back to the construction of matter and how it is based on the atom and the electron. One of the greatest authorities of our day, Robert Andrews Millikan, explains that the difference between all matter, which gives us so many varieties of things, is accounted for by the number and variety of the groupings of negative electrons with their positive charges. These opposite electrical charges in combination constitute the atoms of matter. The positive charge within the atom is sometimes called a proton as stated before.

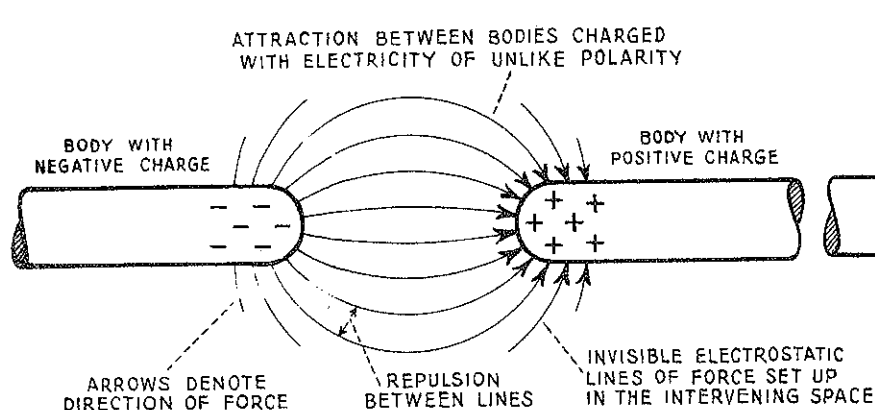


Figure 7

REPULSION BETWEEN BODIES CHARGED WITH ELECTRICITY OF LIKE POLARITY AND EQUAL POTENTIAL

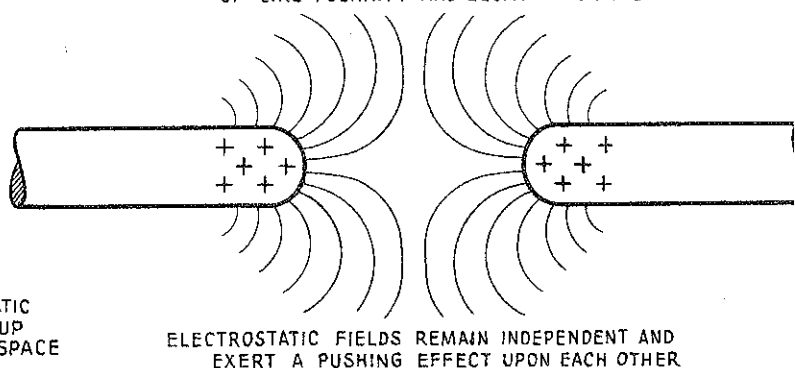


Figure 8

So we learn from the study of the electronic formation of matter that the qualities which permit a particular substance to be recognized are due entirely to a variation of the number of atoms, their size and aggregation in forming the whole mass. We are also told that although the proton of an atom may remain unchanged in position, or quantity, yet it is possible to have perhaps one or more electrons added to or subtracted from those normally revolving within the atom. Any change in the number of electrons in an atom, however, will cause it to become unbalanced electrically. Under such conditions the atoms, and likewise the mass itself, will assume electrical characteristics which are either negative or positive, as explained under the topic immediately following.

It has been proven experimentally by physicists that heat alters the atomic structure of mass. When in the act of rubbing the glass rod with the silk cloth, as in Figure 5, the rubbing set up friction between the materials, and this in turn resulted in a certain amount of heat being developed. Hence, under all conditions we expect friction to generate heat in varying degrees, depending, of course, upon the circumstances surrounding the action. Accordingly, we may expect in the case just cited that the temperature of both the silk and the rod was increased to some extent, although the heat may not have been sufficient for you to detect it. Have you ever noticed

how iron, when subjected to intense heat, will at first change its shape somewhat and later become a molten mass and flow like a heavy liquid.

The electrification of the glass rod according to the electron theory is due to a certain displacement of electrons within the atoms by which they are shifted slightly out of the usual positions they occupy. So long as the electrons remain shifted out of the relative positions in this way then just so long will electric forces (static lines of force) be in evidence in the space about the rod.

WHEN A MASS IS SAID TO BE ELECTRICALLY IN A NEUTRAL, POSITIVE OR NEGATIVE STATE. Referring to Figure 9 you will observe three sketches which show pictorially why unit quantities of a mass are capable of displaying electrical properties at different times.

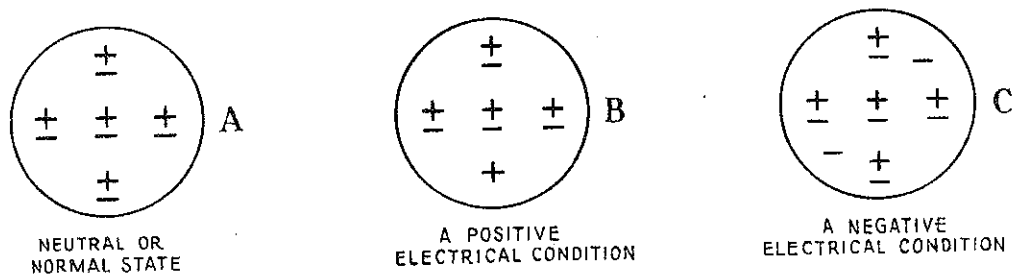


Figure 9

(A) The left-hand drawing, marked (A), indicates that the atoms of this unit mass are in a neutral, or normal state, because the charges are exactly equal in amount and opposite in their nature (+) and (-). Each atom is perfectly "balanced" or "neutralized". When atoms are in this condition, which is a normal condition, no external electrical influence is detectable about the mass. When a body ceases to show electrification it is due to the reuniting of the separated charges.

(B) However, upon looking at the middle drawing, marked (B), you will see that there are five positive and four negative charges. Since the amount of positive charge is greater than the negative this unit mass will be positively charged. It will be recalled that the glass rod in the experiment of Figure 6 was also put into a similar condition of possessing more positive than negative electricity after being rubbed with the silk. This was brought about, it is thought, by a transference of negative charges or electrons from one unit mass to another, or from the glass to the silk. Notice that the unit charge in sketch (B), Figure 9, did not become a positive one because more positive electricity had been added, but rather because a certain amount of negative electrons had been detached from the neutral mass in sketch (A). This means that each atom in mass (B) has given up perhaps one or two of its electrons.

Summarizing these statements tells us, in a few words, that if a mass loses any of its electrons it reduces the amount of negative charge and makes the mass positive. When in this condition the mass sets up a force which is trying to restore its atoms to normal continually by attracting the same number of electrons to itself that it lost. This explains why the mass in sketch (B) is said to be charged positively, or charged to a positive potential.

(C) Now turn your attention to the right-hand sketch, marked (C), where a unit mass is shown with more negative charge than positive. Here the mass is negatively charged. Bear in mind that there are the same number of positive charges in all of the three sketches but that in sketch (B) we took away electrons, whereas, in (C) we have put in two additional negative charges. It is clear that there is a predominance (greater amount) of electrons in (C) over that for a normal condition. The net result in this case, where we have an excess of electrons, is to set up about the mass a force which is continually trying to discharge or give up electrons to re-store its atoms to normal. This explains why the mass in sketch (C) is said to be "charged negatively" or "charged to a negative potential".

THE ELECTROSCOPE

A Simple Experiment to Explain "INDUCTION" and "CONDUCTION". An electroscope is a sensitive device used to detect minute charges of static electricity. A working model can be easily assembled as shown in Figure 10. It consists of a perfectly clean and dry glass bottle fitted with a cork through the middle of which is inserted a stiff copper wire long enough to protrude from both ends of the cork. The upper end of the wire is bent to form a loop while the lower end is bent in an L shape in order to hold a sheet of gold leaf folded in half. This arrangement provides a pair of gold leaves which naturally fall together as illustrated. The cork acts to insulate the metal portions from the glass bottle.

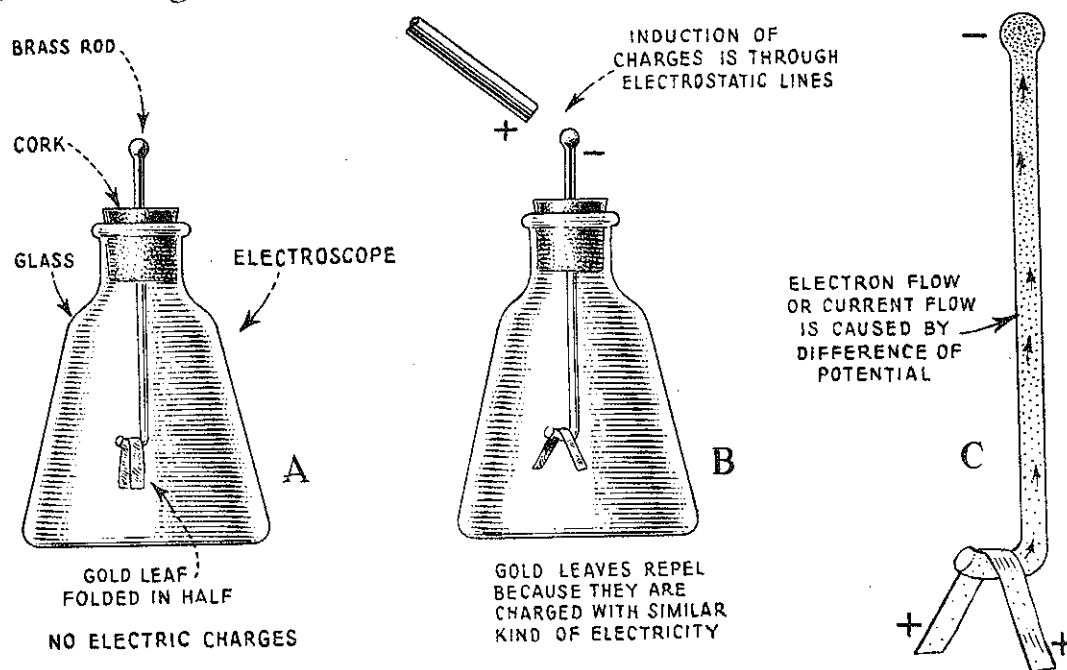


Figure 10

The influence of static electricity upon bodies and the indications of the kind of charges present, that is, whether of positive or negative sign, will be shown by the falling together or spreading apart of the leaves.

To begin our test let us rub a glass rod with silk and then carefully move the rod toward the wire loop without permitting actual physical contact

between the respective surfaces. Notice how the leaves spread apart. This is said to happen because an electric force or charge of like kind is built up on each gold leaf. Since these forces reach out like any electrostatic field and are effective in the region surrounding the leaves we observe this repulsion between them. The nature of the charges and the entire action is explained below in steps for the sake of clearness:

1. It has been arbitrarily decided, as mentioned heretofore, that a glass rod when electrified by rubbing with silk will be charged with "positive electricity".
2. The glass rod induces a charge of opposite kind on the wire loop, hence, the loop becomes charged with "negative electricity".
3. It is seen that the wire and gold leaves taken together actually form a metallic path. In order to make the loop end, "negative" as stated in paragraph (2) just above, it was necessary that electrons be forced to move from one end of this metallic path to the other. Or, we could express the same thing by saying that electrons were conducted through this metal path by reason of the potential force set up at the loop end. Note that the additional electrons which collect at the loop end were originally located at the opposite end, or at the gold leaves. This removal of electrons leaves the latter point deficient in electrons or with a positive charge. This action is shown in the enlarged view in sketch (C)
4. Thus, when the loop end is negatively charged or at a negative potential, the opposite end or gold leaf end becomes positively charged, or is placed at a positive potential, which is the same thing. Comparing both ends there is a difference of potential between them. Consequently, each gold leaf individually possesses a positive charge of equal amount. Therefore, the leaves will diverge or spread apart. This is exactly what was witnessed during the experiment.

It is suggested before putting this experiment aside that you again charge the electroscope by induction using the electrified rod and while the leaves are separated place your finger on the wire loop. The moment contact is made the leaves will fall together showing that your body has neutralized the charge. It would be a very simple matter for you to make an electroscope.

The Difference Between the Terms "INDUCTION" and "CONDUCTION". Again referring to the electroscope experiment, insofar as the wire and gold leaf are concerned, the positive and negative electricity already existed in the atoms which constitute these metal parts. That is to say, the electricity is always present or inherent in the materials. But this electrification was not separated into positive and negative charges, which we know developed at the opposite ends, until the force represented by the charge on the glass rod induced a charge of opposite kind on the wire loop. The force is represented in the drawing by the lines in space connecting the respective surfaces of the charged bodies. The lines are known as the electric or static field as previously explained. Thus, we may have INDUCTION of charges even without the surfaces of bodies actually touching each other.

In the case of the metallic path in the electroscope it happens that the difference of potential set up between both ends forces electrons to move from atom to atom through the metal in a direction from the gold leaves toward the loop end. This entire action is the result of the original attractive force exerted by the positively charged glass rod upon the loop of wire.

One important point just mentioned that should be borne in mind is that in that case where the glass rod is electrified there is no movement of electrons throughout the material, but simply a displacement or slight shifting of electrons within the atoms takes place. On the other hand, in the case of the metal parts, electrons do move or are conducted along from atom to atom of the copper and gold passing from one end of the metal path to the other.

The movement or drift of electrons through the metal parts is actually a flow of current, "or current electricity", which we have already classified. Electrons passing through the metal parts illustrates CONDUCTION.

Accordingly, we may hereafter call the entire path (to include any and all mediums, air, gas, solids, etc.) through which a transference of electricity take place or through which electronic current will flow under a given electromotive force, a conductive circuit.

The electroscope experiment enabled us (1st) to explain the use of the terms "positive", "negative", and "potential", and (2nd) to observe by means of the gold leave that repulsion is always set up between bodies charged with electricity of like kind and (3rd) to demonstrate that positive and negative electricity always appear simultaneously.

Although static electricity and the electrons which account for it are invisible to us, nevertheless, the effects they produce can be indirectly observed under certain conditions. We have explained in a subsequent lesson, titled "Magnetism", how a force which acts between magnetized substances also exhibits identical properties of "attraction" and "repulsion" but in the case of magnetism the force is not derived in the same manner as in static electricity.

A SIMPLE EXPLANATION OF THE TERM POTENTIAL. Electrons may be likened to potential charges. The term "potential" as applied to forces means that energy is stored up in some manner, not necessarily in an object, or mass, but because of the position the object occupies.

To explain this idea let us cite the following comparison: A stone resting on the ground is not capable of performing work when compared to the same stone placed near the edge of a high cliff. The stone, when resting on the cliff, becomes a potential force because, if the stone is pushed, it will fall and a certain amount of work will be done. The work in this case consists of the weight of the mass falling a certain distance through space. Hence, potential deals with a condition in space. The same conditions are true in the case of static electricity and charged bodies. Hence, to make the comparison we would say that potential does not mean the charge itself, nor the mass or body, but rather a condition that exists at a certain point in space. Refer to the drawings in Figures 7 and 8 showing the static forces set up in the space about the charged bodies as indicated by the arrangement of the lines. "Potential" is a term used in connection with forces and

in our work the term is applied to both static electricity and current electricity.

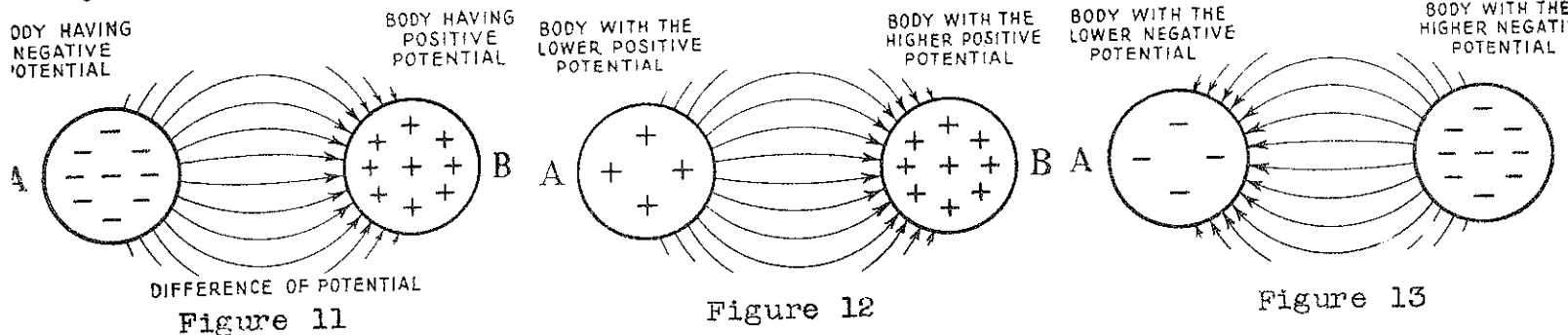
The term "potential" is used in regard to an ordinary dry cell or storage battery. The terminals are connected respectively to electrodes, one of which is said to be at a "positive potential" and the other at a "negative potential". This difference of potential is what provides the electrical pressure and makes the cell or battery capable of performing work. The term potential is also used in business; a potential buyer or potential customer is considered to be a person who has not yet bought any merchandise, but who has the power or is capable of making a purchase if he so desires.

HOW TO USE THE TERM POTENTIAL. ILLUSTRATED BY THREE TYPICAL CASES.

Case 1. In Figure 11, two bodies (A) and (B) are shown, one having a positive potential and the other a negative potential of equal amounts. When discussing the electrical properties or forces set up by two such bodies we say that between them "there is a difference of potential" and because of this condition an electrostatic field is established.

Case 2. Also, we have cases of two charged bodies where each one has a positive potential, but one is at a relatively higher positive potential than the other. See Figure 12. This indicates that bodies (A) and (B) both have a shortage of electrons, but relatively speaking, body (B) has fewer electrons than (A).

Thus (B) will set up a force which places it at a higher potential than (A). Now due to this difference of potential electrons would move from the lower potential point (A) to the higher potential point (B), providing they were



furnished a path or medium through which they could pass. The electrons would move in this direction in their effort to reduce the higher force and bring it down to the level of the lower force. It can be said that (A) is in a more unbalanced state than (B). The medium we refer to could be a copper wire, or any other conducting material, or perhaps a gas, or the atmosphere in certain conditions, and so forth.

Case 3. Also, there are cases of two charged bodies where each has a negative potential, but of unequal amount, as shown by (A) and (B) in Figure 13. If electrons were given a path between these bodies they would move from (B) to (A) since (B) has a relatively greater amount of excess electrons than (A). It is said that (B) is charged to a higher negative potential than (A). Electrons would move toward (A) as suggested in order to equalize the amounts of negative in each body, and, moreover, they would continue pass-

ing from one body to the other until no difference of potential existed between the bodies.

FUNDAMENTAL ELECTROSTATIC LAWS.

We noticed in our experiment with the bits of paper and rubber comb that a body upon which an electric charge had been built up would attract a nearby uncharged body, but after physical contact had been established the attracted body would be repelled. This action occurs because whenever two such bodies actually touch there immediately takes place an equalization of electronic units resulting in the attracted body becoming charged to the same value of polarity as that of the body which caused the attraction. Finally, when both bodies assume like charges of equal value they repel each other. Also, we observed that a body holding a positive charge on its surface would attract a body with a negative charge and vice versa.

Thus we see nature constantly at work tending at all times to maintain unit masses in a state of equilibrium. Since all matter is essentially electrical in substance, then for any condition where the state of rest is upset, nature will exert her forces to restore normal conditions as quickly as possible.

The fundamental laws of electrostatics may be concisely stated as follows:

1. A field of force, called an electrostatic field, always exists in the region about a charged body or between any two bodies or points where a difference of potential exists. Neither a positive nor negative charge is ever produced alone.
2. Bodies holding charges of electricity of similar kind or similar polarity repel each other.
3. Bodies holding charges of electricity of opposite kind or opposite polarity, attract each other.
4. Bodies which have been charged, irrespective of the value of the charge, display an attraction for neutral bodies, that is, bodies which have not been made to exhibit electrical characteristics.
5. An electrical charge can be transferred from one body to any other body (conductors and insulators included) when proper insulation is provided.
6. Electrical or static charges rest only upon the outer surface of a material.

EXAMINATION - LESSON 3

1. (a) What is an element? (b) A molecule? (c) A compound?
2. (a) What accounts for the differences in materials that we are able to recognize the various things on our earth?
(b) Do you think electrical actions could be clearly understood by us all without some knowledge of the electron theory?
3. (a) What is the modern conception of the construction of all matter?
(b) What is the name of the theory that is used to explain the reason for all electrical effects?
(c) Can an electrical charge of one kind exist alone?
4. (a) What do we mean when we say that : A body or mass is in a neutral state?
(b) When in a positively charged state?
(c) When in a negatively charged state?
5. What is a conductive circuit?
6. Into what two general classes is electricity divided and what is the principal difference between them?
7. (a) Why is it that under certain conditions a body will not show any evidence of electrification when we say that all matter is made up of electricity?
(b) What is a flow of current supposed to be according to our modern science?
8. In a few brief sentences tell what you learned from the electroscope experiment.
9. (a) If the atoms of a certain body (called M) contain more electrons than the atoms of another body (called N) which body, M or N, will be charged to the higher potential? And what potential, positive or negative?
(b) In what direction would electrons pass if they were given a path to flow from one charged body to the other as, for instance, if we connected a copper wire between them?
10. (a) State four fundamental laws of electrostatics.
(b) What is an electrostatic field?
(c) Draw a sketch showing two charged bodies, one positive and one negative, showing the electrostatic field, using lines and arrows.
(d) Do electrostatic lines exist within a charged body? Where do they exist?
(e) How may an electrostatic field be produced? Mention two ways you know of.